Review of National Marine Mammal Laboratory Stellar Sea Lion Satellite Telemetry Program

for the

Centre for Independent Experts

prepared by

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June 2004

Introduction & Background

This report addresses the specific goals requested by the CIE. These goals are:

(1) The appropriateness of the programming and deployment strategy of SDRs on juvenile Steller sea lions

(2) The appropriateness of the methods used to retrieve and manage telemetry data obtained from Service Argos

(3) Appropriateness of the stage-based filtering algorithm used by the NMML to detect haul-out periods and to evaluate the geometry and velocity of movements at sea

(4) Determination of whether potential biases have been adequately identified, and whether appropriate measures of statistical uncertainty have been included

In addition the CIE requested a statement on "whether the protocols and analyses represent the optimal approach and best analytical procedures for analysing Steller sea lion telemetry data for the purpose of managing effected Alaskan fisheries".

Background papers were reviewed and detailed discussions were held with NMML scientists at Seattle on 2-3 June 2004.

The structure of this report follows that of the proscribed goals above. However I must first point out that the *scope* of the goals were not well defined. In my view, and this view will persist through out this report, there are two processes involved in what must be a fundamental objective – the spatial usage of *populations*. These may be populations of juveniles or adult females or males.

The first process is one of sampling an individual's movements and behaviour by using SDRs. This process may introduce bias and reduction in accuracy. For example Argos location fixes introduce quantifiable error, and those locations obtained may be biased to certain times of day or animal behaviour. Appropriate location filters or smothers can reduce the influence of Argos errors, and regularisation in the time domain can reduce bias.

The second sampling process is that only a certain *sample* of individuals are tagged, and each has an attribute of sex, age, capture site, season, year, longevity of tracking duration. When *population* usage is inferred (by whatever method) care must be taken that sample animal attributes are representative of the attributes in the population. Or, at least, the prediction models should appropriately weigh the influence of individuals by their attributes. For example, it would be erroneous to infer juvenile usage from just a sample of juvenile males in, say, just the month of June.

Below I comment on how well the goals above have been achieved and make a series of recommendations.

1. Programming and deployment strategy of SDRs on juvenile Steller sea lions

1.1 Two types of Argos satellite telemetry tags have been deployed by the NMML team and other workers on Stellers sea lions. Satellite Data Recorders (SDRs) are manufactured by Wildlife Computers (Seattle) and have been used to collect the majority of the historical information on movement and dive behaviour. Satellite Relay Data loggers (SRDL's) are manufactured by the Sea Mammal Research Unit (St Andrews). The major difference between them is in the way dive and haulout data are stored and relayed. SDR's combine these data into 6-h bins whereas SRDL's relay a *sample* of individual dive or haulout records. However, the evolution of telemetry systems continues - driven by the demands of biologists and technological developments by a number of companies and institutes worldwide. The

forthcoming advent of hybrid GPS technology (e.g. Fastloc (Wild track Telemetry Systems, Leeds)) will provide greater location accuracy, and more frequent locations. The NMML team has the biological and financial ability to influence tag development. However, the use of new systems should not jeopardize the backward compatibility with data already collected

> *Recommendation 1: The NMML team should keep abreast of the latest developments in telemetry systems and should use its expertise and financial buying power to foster new technological developments that would further increase their understanding of Steller sea lion ecology in an oceanographic context.*

1.2 The major constraint in the use of satellite telemetry is the efficient use of limited energy in the battery. SDRs (and SRDL's) permit the user to programme transmission schedules which influence how transmission (and thus locations) are partitioned within a day (allowing for diurnal availability of Argos satellites). The NMML team produced evidence that they had programmed their devices to produce an even spread of locations with in each quarter of the day. This reduced any bias caused the diurnal activity in the seals – such as the times of foraging trips. All 6-h histogram bins of dive information were well represented in the data ashore. However, although the SDR's were programmed to increase emphasis on timelines, a sample of only 60-80% of timeline data were received ashore. This timeline data are important in the proposed filtering process (see below).

> *Recommendation 2: The NMML team should seek to demonstrate whether this sample of timelines is biased towards certain times of day or seal activity.*

2. Methods used to retrieve and manage telemetry data

2.1 The current database is a Jet SQL database engine accessed through Microsoft Access. In the near future, the data will be transferred to Microsoft Sequel Server, which will aid scalability and multi-user access. The database is secure and is regularly backed up.

2.2 Argos telemetry data are regularly imported into the database from a CD and checked by a set of quality control procedures. The table structures allow for the inclusion of data from a wide variety of telemetry sources (not just SDR's). Convenient forms allow for easy input of deployment data (e.g. seal sex, age, etc). One especially useful feature was the facility to include a scanned image of the original field notebook. There were also fields to indicate where the data were published.

2.3 The database allowed easy exporting of data to a variety of statistical and GIS packages. The ease at which oceanographic data could be displayed was impressive.

2.4 While the database was excellently suited to the task, it was disappointing that results from other Steller sea lion researchers was not stored on it. This point is taken up in Recommendation 6 below.

3. Proposed filtering algorithm

3.1 Argos locations fixes (especially from an animal at sea) are irregular in time and often include significant error. Before seal usage patterns are estimated it is essential to carry out two procedures. The first is to reduce the effect of Argos error. The second is to descretize the locations onto the time domain so that clusters of locations, perhaps associated with certain behaviours or times of day, are not given undue weight in estimating usage patterns.

A draft paper by Robson *et al.* entitled "An integrated approach to programming and filtering data from satellite-linked dive recorders" was presented. This described a novel filtering procedure, followed by a descretization procedure.

This is clearly a draft document and I restrict my comments to major items.

3.2 In my view, the paper should only address the primary function - reducing Argos error in track data. The procedure of descretizing in the time domain in a necessary first part in spatial usage estimation – and thus should be considered later.

3.3 The stated aim of the procedure was to 'minimise autocorrelation' in the data. I do not agree that this is an appropriate measure of how well the procedure removes Argos error. Their argument is not convincing. The authors should revisit how the success of their filter may be measured. I suggest that they should consider simulating a series of tracks and then superimposing Argos error (see Thompson et al. 2003). They should then compare how well (and the comparison metric has to be well considered) their filter performs compared with others.

3.4 The procedure is based upon using the SDR timeline data to determine when a seal is hauled out on land – and is thus stationary (but see Recommendation 2 above). Locations associated with this haulout are set to a common place, and are considered as anchor points. High quality at-sea locations are also used as anchor points. The other locations are judged on the basis of feasible swimming speeds from these, reasonably reliable, anchor points. This procedure has an advantage over other filters in the literature that ignore the quality of individual locations.

3.5 In summary, while not necessarily agreeing with the arguments justifying this filter in the draft paper, *I judge the filter as well suited for the task in hand*.

> *Recommendation 3. Robson et al. should complete their paper and submit it to a journal for peer review, taking into account the comments contained above*

3.6 It is important to distinguish between destructive filtering procedures (as described above) and more sophisticated track-smoothing algorithms that have been recently published or are in preparation (Turchin 1998, Jonsen et al. 2003, Thompson et al. 2003, Matthiopoulos et al. in prep). These techniques use the data from all locations and, weighted by the Location Qualities provide a best estimate of the actual seal track. While some of these smoothers are empirical, others are based upon animal movement models and are statistically robust and defensible.

> *Recommendation 4. The NMML team should explore the recent literature in track smoothers and should interact with colleagues in other institutes who are developing such algorithms.*

4. Identification of potential biases and statistical uncertainties

4.1 As I outlined in the Introduction, the two procedures where sampling and measurement error introduce bias and uncertainty in estimating population spatial usage are:

- Sampling movement and behaviour of an individual by using telemetry tags.
- Sampling of individuals from the population of Stellers sea lions

4.2 The reduction of bias and identification of uncertainties in the movement and behaviour of individuals has been dealt with in Sections 1 and 3 above. While I have made specific recommendations that may improve procedures, *NMML's current practice is well suited to collect the required data on individuals' movement and behaviour.*

4.3 To estimate population usage it is essential that the study individuals are representative of the population, and that appropriate statistical models are developed that can incorporate telemetry data from individuals to infer *population* usage.

4.4 Capture methods. NMML and ADF&G have been in the forefront of developing and using novel capture techniques that minimise colony disturbance. These techniques also permit sufficient potential captives to be identified that researchers have within their grasp the ability (luxury!) to capture balanced samples of males/females and age classes.

> *Recommendation 5. The NMML team should encourage the continued refinement of novel capture techniques*

4.5 Sex, age class and sample size. Over 260 sea lions have been instrumented by NMML and ADF&G. These represent a good spread of sexes and age classes. However, neither ADF&G's data, nor data from other agencies or institutes are incorporated in the bespoke database system described in Section 2 above.

4.6 Capture location. Capture has taken place at 32 sites – from Washington State along the Aleutian chain to Russia. This represents a comprehensive geographical spread of locations. It is essential, however, that those regions of the Stellers sea lion distribution that have not been subject to population decline are adequately represented.

> *Recommendation 6. From Sections 4.5 and 4.6: It is essential that efforts be made to incorporate all Steller Sea Lion telemetry data (from whatever agency or institute) into the NMML database for central analysis. While this may require considerable political tact to achieve, the status quo does not allow the full potential of the combined data sets to be realised.*

> *Recommendation 7. Public funding agencies should be lobbied to stipulate that copies of Stellers sea lion telemetry data that are funded from the public purse should be made available to the NMML database. The practical and political ramifications are real and numerous – but none should be insurmountable.*

4.7 Robson *et al.*'s paper limited their analysis of spatial usage to the proportion of foraging time spent within certain buffer zones around predefined Critical Habitat (CH) zones. This was sufficient for the task in hand, but to realise the full potential of the telemetry data collected the natural next step is to estimate the spatial usage (distribution) of the *population* of Stellers sea lions. I suggest that they consider adopting the approach described in the recently published paper by Matthiopoulos *et al*. (2004). Their approach is readily applicable to Stellers sea lions and is statistically robust and defensible. The advantage of this framework is that it produces, in addition to best estimate usages maps, corresponding maps of usage uncertainty. These can identify capture sites, or sex or age classes that are under-represented and that require further data collection to improve usage map confidence intervals.

> *Recommendation 8. The NMML team should explore the recent literature in spatial usage estimation and should confer with colleagues in other institutes who are developing such techniques.*

4.8 It was evident the NMML team was lacking adequate local statistical modelling and biometric support. Such support is vital in carrying out the team's responsibilities and the recommendations in this report.

> *Recommendation 9. The NMML team should immediately appoint a locally based statistical modeller / biometrician who can routinely interact with the other members of the team and who can develop the necessary analytical techniques.*

5. Suitability of protocols and analyses for the purpose of managing effected fisheries

The CIE requested a statement on "whether the protocols and analyses represent the optimal approach and best analytical procedures for analysing Steller sea lion telemetry data for the purpose of managing effected Alaskan fisheries".

Let me first state two difficulties I have with this broad request. First, it is not easy to measure optimality of approach and analytical procedures in a discipline where there are continuous and rapid developments in telemetry systems and analytical procedures. An approach that was optimal yesterday may not be optimal today. Second, the term 'optimal' implies trade-offs between conflicting forces. For instance, we would have a better understanding of Steller sea lion movements and interaction with fisheries if, say, ten times more tags had been deployed. Yet this would incur huge financial and logistic costs and cause increased colony disturbance. So I interpret 'optimality' as conditional on the resources made available.

I consider that the NMML's protocols and procedures are entirely adequate for the task of providing information to reduce seal-fishery interaction. However, that fact that I have made nine recommendations implies that I can see areas which may lead to improvement. These are, however, recommendations, not criticisms.

I would like to emphasise that that recently developed analytical techniques (and techniques still in development) offer the potential to bring further biological signal out of the noisy and irregular track data which can then be used to produced statistically defensible tracks and population usage maps. But this is not the final end point. The NMML team clearly demonstrated that some of the sea lion movements were influenced by local oceanographic conditions (eg gyres). Some of these oceanographic conditions are predictable and some are not. The main point here is that we need to know *why* animals forage where they do, rather than just where they forage. Thus we can build spatially explicit models, which include remotely sensed oceanographic information, to aid foraging distribution estimation. This is a tall order, but the NMML team are already well geared to collecting real time oceanographic information from seals, remotely sensed information and the establishment of concurrent fish/oceanographic surveys.

Finally, I would like to convey, in this otherwise rather dry report, that my general impressions of the NMML team are extremely positive. The team is vibrant, talented and innovative. With adequate continued support and interaction with other institutes, they will continue to deliver first class science (as demonstrated in the papers in Appendix 1) and the appropriate advice required to halt the demise of Steller sea lions.

6. References

Jonsen, I. D., R. A. Myers, and J. M. Flemming. 2003. Meta-analysis of animal movement using state-space models. Ecology **84**:3055-3063.

Matthioloulos, J., B. McConnell, C. Duck, and M. Fedak. 2004. Using satellite telemetry and aerial counts to estimate space use by grey seals around the British Isles. Journal of Applied Ecology **41**:476-491.

Matthiopoulos, J., K. Newman, and B. McConnell. in prep. Likelihood analysis of satellite telemetry data on animal movement.

Thompson, D., S. E. W. Moss, and P. Lovell. 2003. Foraging behaviour of South American fur seals Arctocephalus australis: extracting fine scale foraging behaviour from satellite tracks. Marine Ecology-Progress Series **260**:285-296.

Turchin, P. 1998. Quantitative Analysis of Movement. Sinauer Associates Incorporated.

Appendix 1. Bibliography of materials provided by the Center for Independent Experts

Telemetry white paper prepared by NMFS and ADFG for the North Pacific Fisheries Management Councils Steller sea lion mitigation committee.

Addendum to the 2001 Endangered Species Act Section 7 Biological Opinion on the pollock, Pacific cad, and Atka mackerel fisheries off Alaska. Dated March 26, 2003.

Final Supplemental Environmental Impact Statement on Steller sea lion protection measures dated November 2001**.**

Fadely, B.S., B.W. Robson, J.T. Sterling, A. Grieg, and K.A. Call. In review. Immature Steller sea lion (Eumetopias jubatus) dive activity in relation to habitat features of the eastern and central Aleutian Islands. Fisheries Oceanography:

Merrick, R. L., T. R. Loughlin, G. A. Antonelis, and R. Hill. 1994. Use of satellite-linked telemetry to study Steller sea lion and northern fur seal foraging. Polar Research 13:105-114.

Merrick, R. L., and T. R. Loughlin. 1997. Foraging behavior of adult female and young-of-the-year Steller sea lions (*Eumetopias jubatus*) in Alaskan waters. Canadian Journal of Zoology 75 (5):776-786.

Loughlin, T. R., A. S. Perlov, J. D. Baker, S. A. Blokhin, and A. G. Makhnyr. 1998. Diving behavior of adult female Steller sea lions in the Kuril Islands, Russia. Biosphere Conservation 1 (1): 21-31.

Loughlin, T.R., J.T. Sterling, R.L. Merrick, J.L. Sease, and A.E. York. 2003. Diving behavior of immature Steller sea lions (*Eumetopias jubatus*). Fishery Bulletin 101 (3): 566-582.

Robson, B.W., M.E. Goebel, J.D. Baker, R.R. Ream, T.R. Loughlin, R.C. Francis, G.A. Antonelis, and D.P. Costa. 2004. Separation of foraging habitat among breeding sites of a colonial marine predator, the northern fur seal (*Callorhinus ursinus*). Canadian Journal of Zoology 82 (1): 20-29.

Robson, B.W., A. Greig, J.T. Sterling, and B.S. Fadely. Draft ms. Use of an integrated approach to programming and filtering data from satellite-linked dive recorders: applications for habitat conservation of endangered Steller sea lions.

Appendix 2. Statement of Work

Consulting Agreement Between the University of Miami and
Dr. Bernard McConnell

May 21, 2004

Background

The NOAA Fisheries Alaska Fisheries Science Center (AFSC), National Marine Mammal Laboratory (NMML), requests a review of the analytical process used by AFSC scientists to delineate Steller sea lion dive and foraging behavior using satellite-linked dive recorders (SDRs). The data are used extensively by NOAA Fisheries to facilitate fisheries management in Alaska and to delineate critical habitat as required under the Endangered Species Act. The telemetry studies have been the focus of recent litigation, and were identified in court as a critical link in the Agency's decisions pertaining to Alaskan fisheries. It is important that Agency scientists use the best analytical methods available, and that their analysis be accepted by the peer community and Agency constituents.

A critical part of the analysis is the determination of the animal's location when foraging; the analysis leading to this determination requires data sorting and assumptions that can be viewed by constituents as equivocal. NMML developed a transmission protocol for SDRs to collect high-quality location data associated with six-hour sampling intervals. A stage-based filtering algorithm was also developed that used surface-timeline data to detect haul-out periods and iteratively evaluate the geometry and velocity of movements at sea relative to predefined threshold values. The filter also considered Argos location class of adjacent locations as a factor in determining which locations to remove. After filtering, locations were sub-sampled at 6, 12 and 24-hour intervals based on Argos location quality, and the effect of sampling design and filter algorithm was assessed using Schoener's ratio of spatial autocorrelation. The AFSC therefore requests an independent review of this analytical process.

General Requirements

The consultant will need to be thoroughly familiar with various remote sensing methods and basic computer programming and will travel to Seattle, WA, to meet with the involved scientists and to review the input data set and the analytical process. The AFSC will provide copies of relevant documents and a description of the analytical framework (see Appendix I).

The consultant shall review the Steller sea lion satellite telemetry data and the analytical procedures used to filter the data focusing on the following issues:

1.The appropriateness of the programming and deployment strategy of SDRs on juvenile Steller sea lions;
2.The appropriateness of the methods used to retrieve and manage telemetry data obtained from Service Argos;
3.The appropriateness of the stage-based filtering algorithm used by the NMML to detect haul-out periods and to evaluate the geometry and velocity of movements at sea; and
4.Determination of whether potential biases have been adequately identified, and whether appropriate measures of statistical uncertainty have been included.

The consultant shall be provided with background material (listed in Appendix I) to assist in addressing the aforementioned issues. NOAA Fisheries shall provide an agenda prior to the meeting at the AFSC.

The consultant shall conclude in a written statement whether the protocols and analyses represent the optimal approach and best analytical procedures for analyzing Steller sea lion satellite telemetry data for the purpose of managing affected Alaskan fisheries.

Specific

The consultant's duties shall not exceed a maximum total of 12 days - several days for document review, two days to attend a meeting at the AFSC, and several days to produce a written report of the findings. The consultant may perform most of the review, analysis, and writing duties out of the consultant's primary location, apart from the meeting, which shall be held at the AFSC. The written report is to be based on the consultant's findings, and no consensus report shall be accepted.

The itemized tasks of the consultant consist of the following.

1. Reading and considering the documents (listed in Appendix I) that provide context and background on the Steller sea lion telemetry issue.

2. Reading and analyzing the draft manuscript on the stage-based filtering algorithm and other documents describing NMML's telemetry data filtering protocol and data analysis.

3. Attending a two-day meeting in Seattle, Washington, from June 2-3, 2004, to discuss the review background material, the input data set, and the analytical process with AFSC scientists. The meeting will be held in Room 2039 of Building 4 of the Alaska Fisheries Science Center at Sand Point.

4. No later than June 18, 2004, submitting a written report[1] that addresses issues 1-4, as detailed in the above General Requirements section. See Annex I for additional details on the report outline. The report shall be sent to Dr. David Die, via email at ddie@rsmas.miami.edu, and to Mr. Manoj Shivlani, via email at mshivlani@rsmas.miami.edu.

Signed_____
Date_____

[1] The written report will undergo an internal CIE review before it is considered final.